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(54) An image projection system for use in large field of view presentation

(57) Image display apparatus comprising a screen 2, a plurality of projectors 9 and a plurality of beam splitters 10, the image display apparatus being such that each projector 9 has its own beam splitter 10, and the projectors and their beam splitters are arranged to be around an observer 3 in such a way that the equivalent projection point or points are at or near to the observer's eyepoint 3 so as to form an image at a surface of the screen 2, whereby the image is substantially geometrically correct when viewed from a location at or near to the observer and whereby there is no need for substantial pre-distortion of the image within the projector.

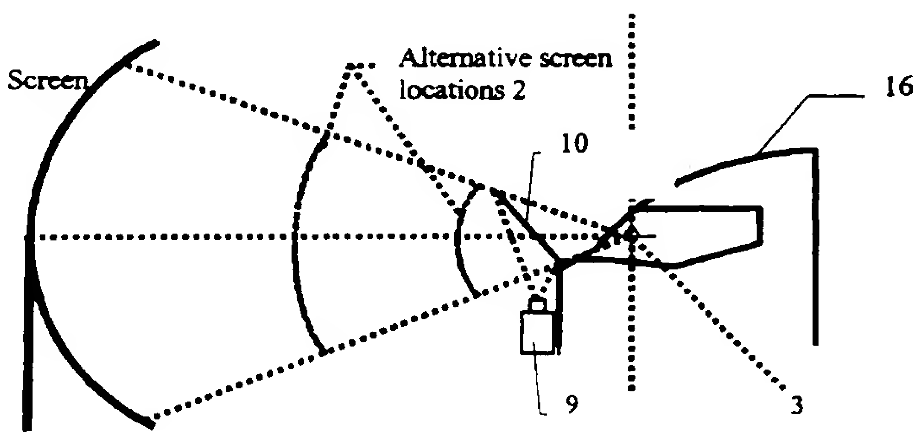

Fig. 9

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

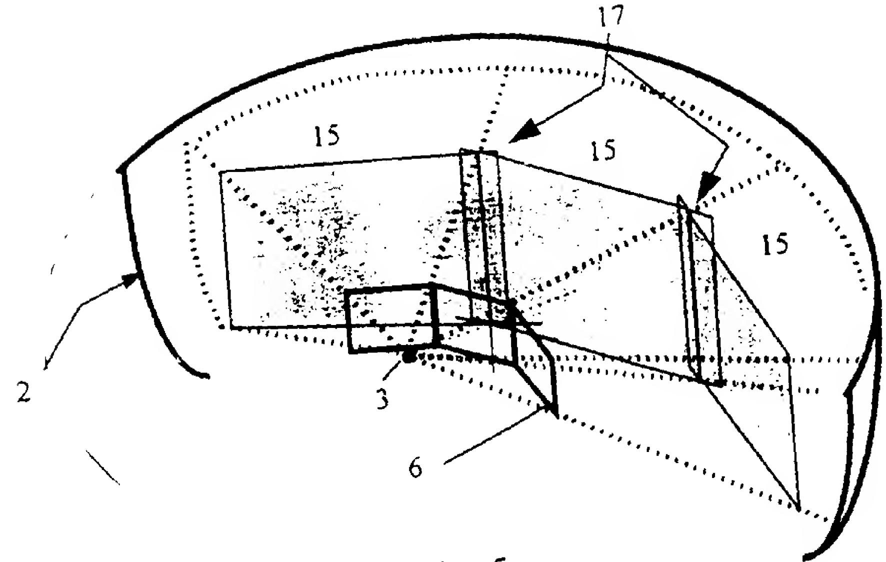

Fig. 5

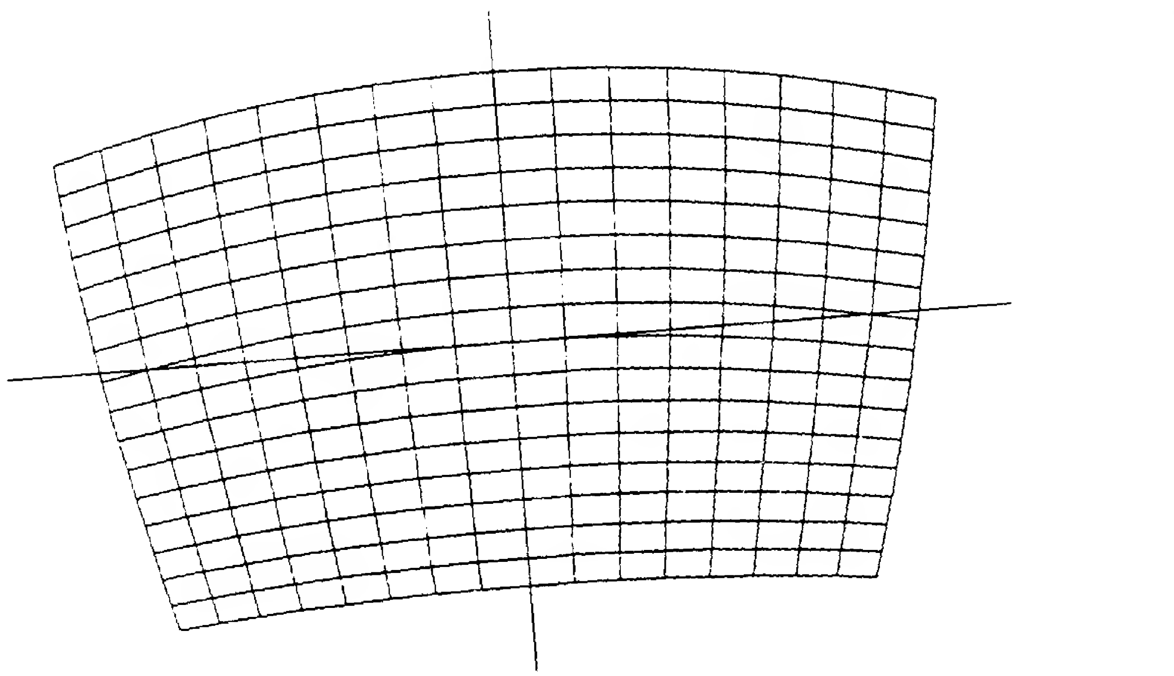

Fig. 6

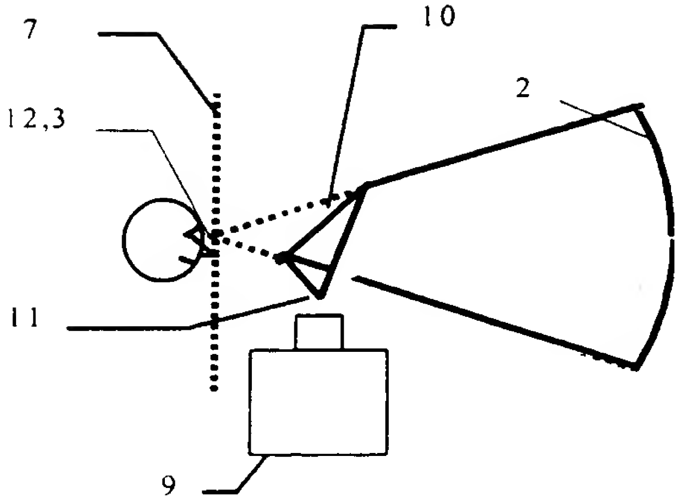

Fig. 7

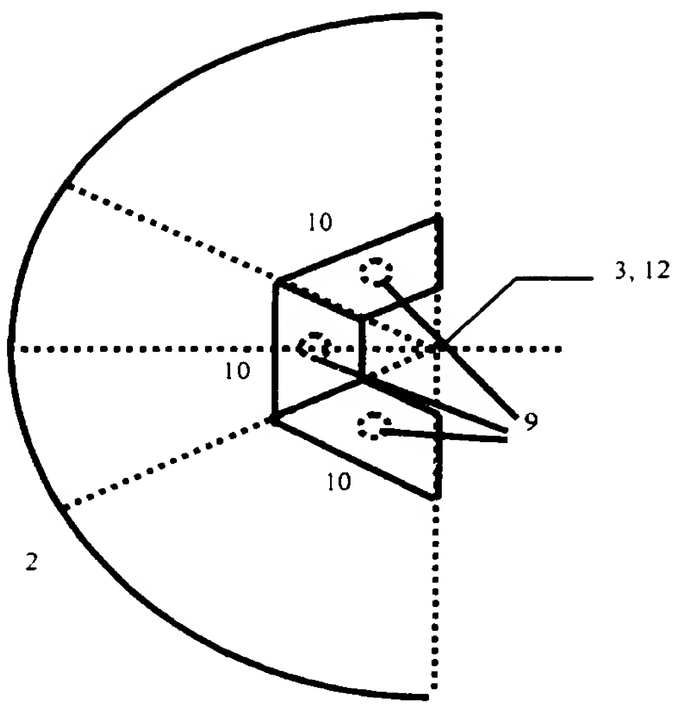

Fig. 8

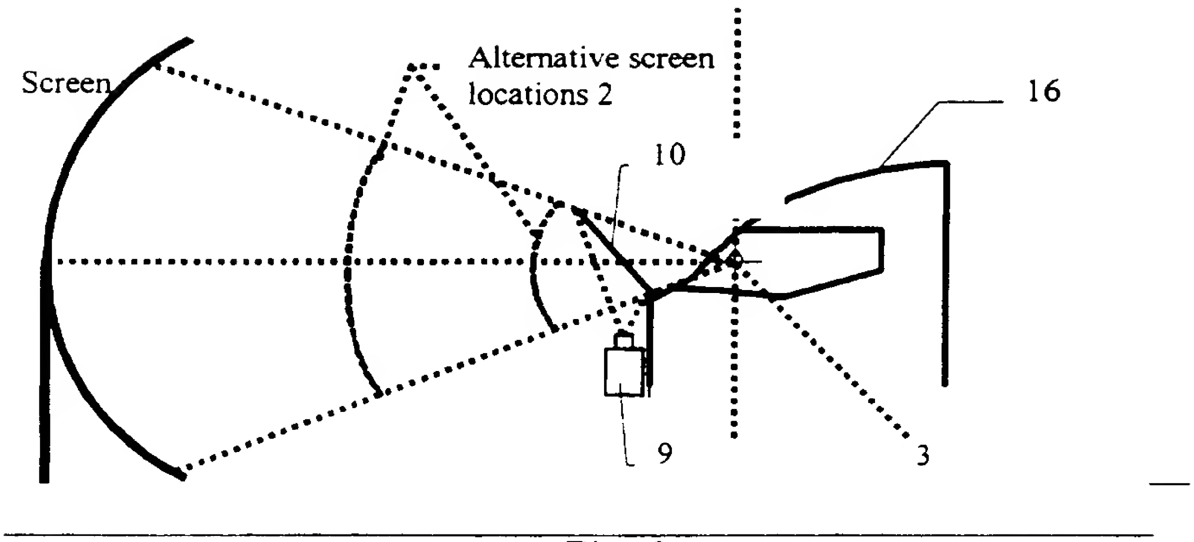

Fig. 9

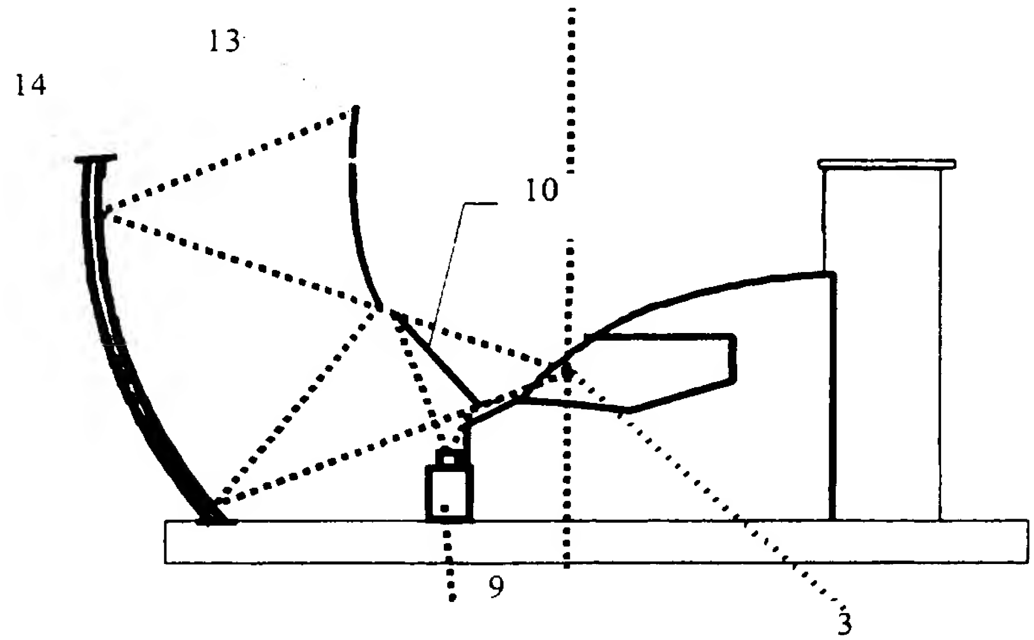

Fig. 10

IMAGE DISPLAY APPARATUS

This invention relates to image display apparatus, for example to large field-of-view display apparatus that may be used, for example, in flight, vehicle, marine and leisure simulators.

Flight or other simulation, for example for training or research, often requires that a high fidelity visual system be fitted to the simulator. The high fidelity visual system is known as an out-of-the-window visual system. This visual system comprises three major components, namely a computer image generator, a simulated real world database, and an image display system. The simulated real world database is loaded into the computer image generator. The image display apparatus is used to present a real-time out-of-the-window scene to a person such as a pilot, driver or other operator in the simulator. The input to the image display apparatus is provided by the computer image generator, which the latter forms in real time, in response to stimulus from the operator. Many approaches to out-of-the-window displays are used, including direct-view graphics monitors, collimated monitor optics, real image wide-angle projection and collimated wide-angle projection.

A projector display system may comprise one or more projection devices and an optical system that provides a surface upon which an image is formed and which a person can view, either directly or indirectly. Optical considerations, limitations of display technologies and other factors such as computer image generator limitations, normally result in the need to use multiple image generation channels and hence projected display channels to form a single image to the subject. Formation of a single image from multiple images requires that projected images from each channel at least abut, and that information, for example, scenes, objects and features, displayed by each projected channel correlates both with the simulated real-world co-ordinate system and with adjacent channels. It is normal in high fidelity simulation that adjacent projected channels overlap by a margin sufficient to allow the blending of image contributed by each channel, a process whereby the image is faded out at the edge of adjacent channels such that intensity variations are minimised to form a seamless continuous image over the entire field of view.

In one non-limiting embodiment of the present invention there is provided image display apparatus comprising a screen, a plurality of projectors and

a plurality of planar beam splitters, the image display apparatus being such that each projector has its own beam splitter, and the projectors and their beam splitters are arranged to be around an observer in such a way that the equivalent projection point or points are at or near the observer's eye point so as to form an image at a surface of the screen, whereby the image is substantially geometrically correct when viewed from a location at or near to the observer and whereby there is no need for substantial pre-distortion of the image within the projector.

The image display apparatus may be one in which the beam splitters are polarising beam splitters and are aligned to reflect substantially the full light output of a suitably polarised projector to the screen surface, thereby reducing image intensity loss.

The screen may comprise a specular reflective coating, thereby maximising the amount of light arriving at or near the observer. The specular reflective coating may be a retro-reflective specular reflective coating.

The image display apparatus may be one in which the projectors are located below the plane of the observer eye level.

The image display apparatus may include a wide-angle collimating mirror, the image display apparatus being such that the image is formed via the wide-angle collimating mirror on to the screen surface, the image being substantially geometrically correct and collimated when viewed from the location at or near to the observer.

The present invention thus relates to projection displays, both real-image or direct view, and to collimated projection display systems. The image display apparatus may form part of simulators that require an image to be presented to an observer or group of observers, the image being required to represent either a real-world scene or other similar scene. For leisure ride simulators, the scene may be imagery in concept. Computer-generated databases may be employed for the purposes of design or visualisation of systems, buildings or architecture. If desired, the simulators may give educational displays for example of historical or astronomical content, where a cab or cockpit is not necessarily required.

Embodiments of the invention will now be described solely by way of example and with reference to the accompanying drawings in which:

Figures 1 and 2 illustrate a typical direct view front projection system;

Figures 3 and 4 illustrate a collimated projection system;

Figure 5 illustrates an operation required of a display system;

Figure 6 illustrates a typical distortion;

Figure 7 illustrates image display apparatus of the present invention in the form of an optical arrangement of projectors and beam splitters that are placed around a simulator cab or cockpit;

Figure 8 is a plan view of a number of projection channels each having a separate beam splitter, for creating a relatively large field of view;

Figure 9 shows a projector/beam splitter arrangement of the present invention situated around an aircraft simulator cockpit; and

Figure 10 shows another projector/beam splitter arrangement of the present invention situated around an aircraft simulator cockpit.

Referring to Figures 1 and 2, there is shown a typical direct view front projection system, where three projectors 1 form a continuous image directly on a screen surface 2 visible from a simulator design eye point 3. As is commonly found in simulation displays, three-tube cathode ray tube projectors 1 are

used, projecting through the vertical axis of the screen. Lens design considerations of cost and performance generally result in projection cone angles. These projection cone angles are the angles occupied by the light emitted from the cathode ray tube-lens combination measured from a lens reference point. The projection cone angles require that the projectors themselves are located at a distance greater than the horizontal screen radius.

Figures 3 and 4 illustrate a collimated projection system, also using cathode ray tube projectors 1. In Figures 3 and 4, a person views the image formed on the outer surface of a rear projection screen 4, via a spherical collimating mirror 5. The rear projection screen 4 is generally of significantly smaller radius than the screen of the front projection system 2. Therefore, for similar field-of-view coverage and cathode ray tube/lens characteristics, the cathode ray tube projectors 1 must be placed closer together. In the example shown in Figures 3 and 4, the cathode ray tubes are arranged vertically in line, to enable closer spacing of the projectors, although the cathode ray tubes are still placed behind the screen horizontal centre of curvature.

Such systems must be designed such that, when fitted to the simulator, the resultant image fulfills

the total requirement. Particular parameters within the total requirement that relate to the present invention are as follows:

1. **FIELD OF VIEW**

The subtense of the continuous image measured at person's eyepoint.

2. **GEOMETRIC ACCURACY**

Objects and features of the image should appear to be correctly positioned within a given limit when measured at the person's eyepoint.

3. **EDGE MATCH ACCURACY**

Objects and features that exist in the region of the boundary between display channels should not exhibit discontinuities as they pass through the boundary.

4. **CHANNEL OVERLAP LUMINANCE VARIATION**

Where the projected channels overlap and hence superimpose image information in the boundary regions, the resultant variation in luminance, where there should ideally be no variation, should be within specified limits.

Referring now to Figure 5, ideally all projection channels should project from the eyepoint. Figure 5 illustrates the equivalent operation required of a display system. Each computer image generator channel outputs data equivalent to information representing

imagery as seen through a rectangular window from the design eye point 3 when viewing a simulated real world. This window may be referred to as a logical display plane 15. Image data are typically presented in the form of video signals suitable for display by an electronic display device, for example a computer monitor or video projector. In practice, the designed angled subtense of each logical display plane is typically greater than the actual field of view coverage required for the corresponding channel, to provide overlap 17 that allows for fading or blending together of adjacent channel edges in the realised display system by optical or other means to form a seamless total image. If it were possible to project each channel's image from the pilot or driver eyepoint on to a screen surface 2 using image projection lenses that result in equal image subtense to the corresponding channel subtense, then the image would always be presented correctly to the eye, as the rectangular subtense of the original windows are replicated from the eye. This would be true regardless of the shape or distance of the screen from the subject.

In the example shown in Figures 1 and 2, the projectors 1 are located behind and above the observer, projecting through the vertical screen axis.

This is the typical result of the design process whereby available cathode ray tube-lens projection angles and three dimensional layout of projectors with screen and other structures are arranged to produce image coverage of the desired field of view whilst avoiding shadowing of the projected images either by simulator structures or projection devices themselves. If the projectors' lenses project rectangular images equal in subtense to the intended channel subtense, but viewed from the lens projection point rather than the design eye point, then the image as viewed by the observer is severely distorted. This is a result of the separation between the projection and eyepoints and that the screen is at less than infinite distance from the observer. If the screen were flat, the distortion would be prominently in the form of size or angular subtense, horizontal trapezium and vertical linearity. If the screen were curved, as shown, further major distortions of curvature would exist. Typically, the distortions are compensated by exploiting the ability of cathode ray tube projectors to apply corresponding counter-distortions at the projection image plane, such that once formed on the screen, the image geometry is correct.

Figure 6 illustrates a typical distortion that may be applied. Such an arrangement, although

successful in a number of installed systems, suffers from the following drawbacks.

1. Cathode ray projectors are not stable with time or temperature and accordingly suffer variability of image shape, size, position and registration of colours, the latter characteristic resulting from a typical arrangement whereby a full colour image may be created by superimposing separate red, green and blue images.

2. Cathode ray tube projectors suffer a limited light output capability when compared to more recent projection technologies such as those that employ liquid crystal devices and digital micromirror devices.

3. Projection devices must typically be placed above and behind the driver cab or cockpit. A particular drawback of this is that the total height of the simulation system is significantly increased above that of the cab or cockpit. This is a particular limitation when attempting to build such a simulator into an existing building facility with limited ceiling height. Another drawback is that the projectors are also located at a considerable distance from the base of the simulator cockpit. For the case where the cockpit may be placed on to a movable platform, for example to allow simulation motion

effects to be imparted on the observer, there is consequently a high mass moment of inertia that the movable platform must therefore be capable of supporting, in addition to the remainder of the simulator, and meet the required system motion requirements.

4. The full area of the projection device image plane is not utilised, as a non-rectangular inset area must be used to allow for image pre-distortion that compensates for the distortion described above.

5. Screen services with specular characteristics may not readily be used without careful consideration of differential effects between adjacent projection channels' images when the observer's head moves.

The image display apparatus of the present invention may take the form of an optical arrangement of projectors and planar beam splitters that are placed around a simulator cab or cockpit as shown in Figure 7. In Figure 7, an observer 8 views a screen 2 upon which an image is formed. For one projection channel, the projector 9 projects its beam on to the screen 2 via a planar beam splitter 10 placed in front of the cockpit or cab. The beam splitter 10 is arranged such that the projector 9 is placed at a level below the observer 8 eye level, projecting upwards towards the beam splitter 10. Obviously, it

would be possible to envisage an arrangement whereby the beam splitter 10 is rotated by about 90° such that a projector 9 placed above eye level, projecting downwards could be used. For the purpose of describing the operation of the system, a beam splitter can be described as an optical plate that splits any incident beam of light into two outgoing beams, sharing the beam energy between the two outgoing beams. When arranged at a particular angle with respect to the incident beam, typically 45°, the incident beam energy is split equally between the outgoing beams. Therefore, in the arrangement shown in Figure 7, the beam splitter 10 may be considered in the first instant as a lossy mirror, from the projection point 11, that is less than 100% of the incident beam is reflected. The projected beam is thus reflected or folded towards the screen 2. Light emitted from the screen 2 towards the eyepoint 3 will then pass through the beam splitter 10, which appears to the beam as a lossy window, that is less than 100% is transmitted.

An important characteristic of the arrangement is that the arrangement provides an equivalent projection point 12 within the cockpit or cab from which an imaginary projector could be positioned to produce the same image on the screen. By suitable arrangement of

the beam splitter 10, the projector 9 and the screen 2, this equivalent point 12 could be the actual observer's eyepoint 3, a situation indicated in Figure 7. The observer 8 therefore sees an image of content and total angular subtense identical to that which, if it were possible, could be observed from the projection point itself. Therefore, if the image content, produced perhaps by a computer image generator, is arranged to represent that viewable through an imaginary window 6 (see Figure 5) of equal subtense at the design eyepoint, then the resultant image observed will be geometrically correct without any need for projector image distortion. Of course, image content could be produced by a camera fitted with an appropriate lens to cover equivalent field of view and perhaps a larger field of view, whereby the area equivalent to the projection angle is extracted by software, electronic or optical means.

It will be apparent that the image display apparatus of the present invention enables a number of benefits as follows to be obtained.

1. Because no image distortion at the projector is required to meet acceptable image geometry, fixed-matrix projectors may be employed, such as those based on liquid crystal devices or digital micromirror devices technologies. Such projectors are available

that offer high light output, low cost, high pixel visibility, and combinations of these benefits. Furthermore, such projectors are inherently stable and highly reliable as compared to cathode ray tube projectors. Furthermore, such projectors may be obtained that are of substantially lower mass than typical cathode ray tube projectors.

2. The full area of the projection device image plane is utilised as none is "wasted" by only employing a best-fit distorted image portion, as necessitated in typical off-axis projection arrangements.

3. By placing the projectors at a low level, as shown in Figures 7, 9 and 10, the total height of the simulator may be substantially less than conventional solutions where projectors are placed at off-axis locations well above the cockpit or cab.

4. A screen surface with specular characteristics may readily be used. This is a result of the fact that the projection point is effectively the observer's eyepoint, or close to it. Therefore, reflected light is optimised towards the observer by nature of the basic arrangement. A particular example would be the use of a retro-reflective screen surface, which has the characterising quality of reflecting any incoming beams back along the incident axis. Here,

the layout would be substantially insensitive to inaccuracies in the system construction.

5. By placing the projectors at a low level as shown in Figures 7, 9 and 10, the mass of the projection system is located at a level low down and close to the base of the simulator cockpit. For the case where the cockpit may be placed on to a movable platform, for example to allow simulated motion effects to be imparted on the observer, the mass moment of inertia is much reduced as compared to the conventional solutions, for example as shown in Figures 1 and 3. This benefit is further enhanced when considering the availability of lightweight projectors as mentioned above. An important consequence here is that the cost of the motion system may be substantially reduced or, at a given cost, the motion capability substantially increased in acceleration and rate terms.

Referring now to Figure 8, in order to create a relatively large field of view, a number of projection channels could be arranged, each with a separate beam splitter. Figure 8 illustrates a plan view of such an arrangement, where each channel is similar to that shown in Figure 7. In Figure 8, there is shown a projector 9 and its beam splitter 10. Also apparent from the layout shown in Figure 8 is that the multiple projection points all have an equivalent point at or

near the observer or design eyepoint 3, which is a preferred but not exclusive arrangement. Having coincident or near-coincident equivalent projection points ensures that the correct image geometry is viewed throughout the total projected scene and, if a screen surface that exhibits specular characteristics is employed, consistent reflections will result for all channels.

A natural shape for each beam splitter 10 is a trapezoid, to enable multiple beam splitters to both encompass the respective projection beams and to allow abutment with adjacent beam splitters. By suitable selection of projector lens focal length, each image channel can be arranged to at least abut on the screen surface 2. It is also possible with slight degradation of image geometry, by bringing forward the projector 9 along its projection axis, to have each image channel partially overlap its adjacent channel or channels. Optical masking or electronic modulation means could then be employed to ensure constant image intensity throughout the overlap region, resulting in an essentially seamless image from multiple projectors.

With the image display apparatus of the present invention, the beam splitter causes loss of image intensity in that 50% (or more) of a ray energy from

the projector to the beam splitter passes through and is lost, and 50% of a ray energy from the screen to the observer is reflected away and is thus lost, thus resulting in 75% or more loss through the beam splitters alone. This effect may be alleviated if a projector that outputs polarised light is employed. The beam splitter could then be of the polarising type, with its polarising axis arranged with respect to the projector incident beams such that substantially non-attenuated beams are reflected towards the screen. Around 50% is still lost from the screen to the observer, but the total loss could be less than 60%.

Referring now to Figure 9, there is shown a projector 9/beam splitter 10 arrangement situated around an aircraft simulator cockpit 16, although a similar arrangement with a truck, car or other enclosure (including none at all) may be employed. A real image is formed on a screen surface 2 which is viewed by an observer 8 from the cockpit 16. Multiple channels would be realised in the same way as shown in Figure 8, with a cockpit 16 placed with the pilot eyepoint or design eyepoint 3 at or near the projection point. The screen 2 is preferably curved and continuous over the total displayed field of view point. Spherical, toroidal, cylindrical and conical

screen shapes may be employed, preferably where the centre or centres of curvature are at or near the observer's eyepoint location. Figure 9 illustrates a spherical screen 2. The radius of this screen 2 has a minimum value that allows fitment around the beam splitter arrangement. The minimum radius would also result in the lowest screen mass (and hence cost) and the lowest mass moment of inertia (and hence motion system cost) and greatest screen luminance for a given projector light output. However, larger radii may be used according to application requirements.

Referring now to Figure 10, a projector 9/beam splitter 10 arrangement is again shown and situated around an aircraft simulator cockpit 16. However, instead of forming the image directly on a screen surface, the projector beams are directed on to a curved front projection screen 13, that replaces the rear projection screen 4 of Figures 3 and 4, via the curved mirror 14. This arrangement is a reversal of the convention collimating optical system when considering the projection path. However, from the observer position or design eyepoint 3, the arrangement appears to be the same, with the image being collimated. Certain adjustments to the mirror 14 shape and projection lens design are preferable to obtain satisfactory performance, particularly as

regards focus of the image on the front projection screen.

It is to be appreciated that the embodiments of the invention described above with reference to the accompanying drawings have been given by way of example and that modifications may be effected.

CLAIMS

1. Image display apparatus comprising a screen, a plurality of projectors and a plurality of planar beam splitters, the image display apparatus being such that each projector has its own beam splitter, and the projectors and their beam splitters are arranged to be around an observer in such a way that the equivalent projection point or points are at or near the observer's eyepoint so as to form an image at a surface of the screen, whereby the image is substantially geometrically correct when viewed from a location at or near to the observer and whereby there is no need for substantial pre-distortion of the image within the projector.

2. Image display apparatus according to claim 1 in which the beam splitters are polarising beam splitters and are aligned to reflect substantially the full light output of a suitably polarised projector to the screen surface, thereby reducing image intensity loss.

3. Image display apparatus according to claim 1 or claim 2 in which the screen comprises a specular reflective coating, thereby maximising the amount of light arriving at or near the observer.

4. Image display apparatus according to claim 3 in which the specular reflective coating is a retro-reflective specular reflective coating.

5. Image display apparatus according to any one of the preceding claims in which the projectors are located below the plane of the observer eye level.

6. Image display apparatus according to any one of the preceding claims and including a wide-angle collimating mirror, the image display apparatus being such that the image is formed via the wide-angle collimating mirror on to the screen surface, the image being substantially geometrically correct and collimated when viewed from the location at or near to the observer.

7. Image display apparatus according to claim 1 and substantially as herein described with reference to the accompanying drawings.

The Patent Office

Application No: GB 9719268.6
Claims searched: All
Examiner: Joe McCann
Date of search: 10 November 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4F(FCW,FDD,FDX,FJS);G2J(J41,JAS)

Int Cl (Ed.6): H04N(5/74,9/31);G03B(21/12,21/28);G09B(9/30,9/32,9/34)

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2187911A (SINGER-LINK MILES CORP) - see fig 2	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.